

Vermont Phosphorous Innovation Challenge

Project Title: Ultrafiltration of Dairy Manure for Phosphorus and Pathogen Control

Principle Investigator:

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Project Overview: This project seeks to implement an ultrafiltration system on a Vermont dairy farm to remove >95% of the phosphorus, >99% of the suspended solids, and >99.9% of pathogens in liquid manure, producing a transparent liquid ideal for field application (80% of the initial manure volume) and a concentrated fertilizer that is readily transportable (20% of the initial manure volume). By concentrating phosphorus, this technology allows the farm to more economically apply phosphorus on lands that are further away and typically lower in soil phosphorus, as well as transport the material to nearby compost facilities for later export from the watershed.

Project Objectives:

- 1. Demonstrate the efficacy and cost-effectiveness of a stainless steel, tubular ultrafiltration system to process liquid dairy manure into “UF Permeate” (aka “tea-water”) with very low levels of phosphorus and “UF Concentrate”**
 - a. This project will involve processing liquid dairy manure from multiple Vermont farms through a pilot-scale ultrafiltration unit to collect actual data on filter performance and nutrient levels in the influent and each product stream. This will allow precise calculation of the amount of phosphorus that can be removed and concentrated onsite as well as the cost per pound. Samples of the UF concentrate will be taken to local composters and fertilizer manufacturers for use in trials for product development, and the value of the concentrate determined through a market analysis.
- 2. Demonstrate the benefits of on-site ultrafiltration to the farm owners**
 - a. By concentrating the phosphorus and a portion of the total nitrogen in liquid manure into ~20% of the initial volume, the farm will benefit from:
 - i. Reduced hauling and spreading costs, especially for bringing manure nutrients to fields that are further away
 - ii. Potential to use lower cost spreading methods for UF permeate (with no suspended solids or pathogens, spreading through irrigation equipment is greatly improved and can be done at lower cost)
 - iii. Potential for new revenue source from sale of concentrated fertilizer to composters, fertilizer manufacturers, and/or organic producers
 - iv. Potential for higher crop yields due to improved agronomic practices that reduce runoff
- 3. Demonstrate how onsite ultrafiltration of manure benefits the environment/watershed:**
 - a. Reduced runoff of phosphorus into nearby surface waters due to improved agronomic practices (application timing to maximize uptake, application to soils with lowest

phosphorus levels, placement of concentrated fertilizer onto fields is less mobile than more dilute manure)

- b. Reduction in the spreading of *E. coli* and other pathogens into groundwater and surface bodies
- c. Reduced soil compaction due to improved spreading practices
- d. Reduced truck traffic on roads (community benefits)

Overall, successful implementation will demonstrate that this technology is a cost-effective solution for improving water quality in Vermont while concurrently helping farms become more economically sustainable. The data collected and the outreach done as part of the implementation (through tours and educational events) will help educate nearby farmers and others about this technology, helping increase its rate of adoption. This work will also provide the foundation upon which to build a hub-and-spoke system in which dairy farms use onsite ultrafiltration to concentrate phosphorus and then transport some or all of it to a central location for processing (which may include composting, blending, drying, packaging, etc.). We believe this approach will ultimately provide the most benefits for the farm, the local economy, and the waterways of Vermont.

Technology Description:

Digested Organics has pioneered the use of a unique stainless-steel ultrafiltration system for dairy manure over the last three years of R&D and commercial experience. We have installed a full-scale commercial system at Majestic Crossing Dairy (850 cows) in Sheboygan Falls, WI that has now been operational for over 18 months with excellent results. Unlike other technologies that aim to separate phosphorus and suspended solids from dairy manure using chemicals/polymers (e.g. centrifuges, dissolved air flotation, belt filter, etc.), our system uses no chemicals for separation. Instead, liquid manure is pumped through a series of porous stainless steel tubes with an average pore size of 0.02 microns. Particles larger than 0.02 microns remain inside the tube, while water and dissolved solids pass through the wall of the tubes as “UF Permeate” or “tea-water”, an amber-colored liquid shown in the picture below. Through testing on dozens of manures, our filtration technology routinely produces UF permeate with 95% less phosphorous, 99% fewer total suspended solids, and 99.9% fewer pathogens compared to the raw liquid manure. Typically, 80% of the volume of the raw liquid manure can be recovered as UF permeate, with 20% recovered as UF concentrate. As a result, phosphorus is highly concentrated into a small volume as a pumpable, high-solids slurry.

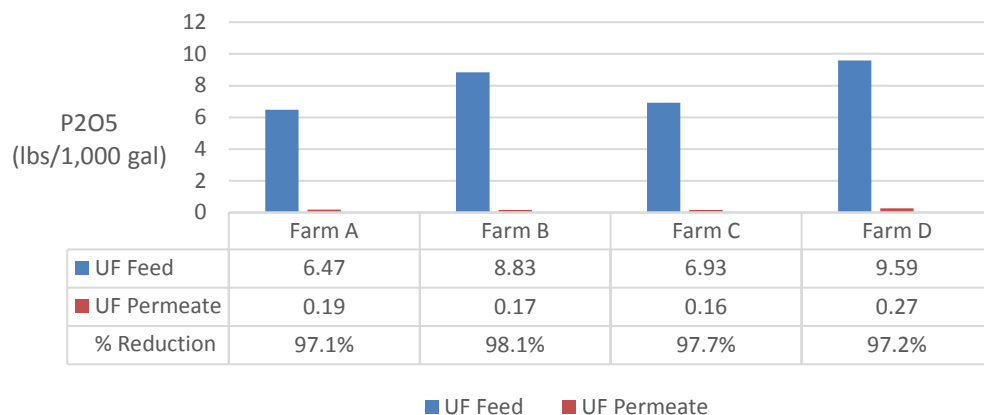


Picture of Ultrafiltration module installed at Majestic Crossing Dairy.

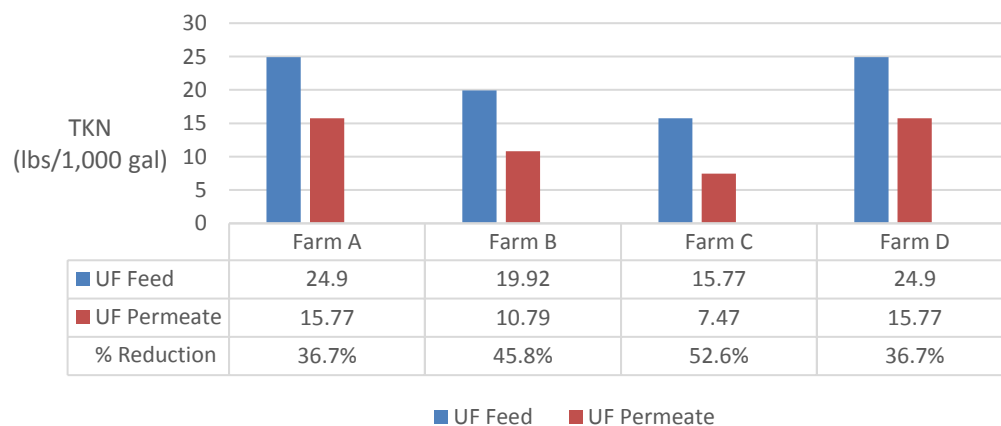
The system is also very simple with few moving parts (just two centrifugal pumps), so it is robust and built to last on a farm for 10-15 years without requiring replacement parts. It also achieves a higher level of phosphorus removal than any other process we are aware of (see graph below of testing done on four farm's manures). While adaptive management strategies like buffer strips and cover crops can be helpful, we believe actually separating the phosphorus from the manure and then either applying it very strategically and precisely so as to minimize runoff or simply shipping it out of the watershed is a more cost effective and guaranteed strategy for water quality improvements. This program will be the first to implement ultrafiltration of dairy manure in Vermont.

The graphs below show the concentration of nitrogen and phosphorus in the digested manure (the “UF Feed”) and UF permeate from four dairy farms in Wisconsin. These data show that **the UF system removes about 36-52% of the total nitrogen** (mainly the organic fraction) **and 97-98% of the phosphorus**, producing a tea-water ideal for irrigation/spreading along with a smaller concentrate product for targeted land application or use in compost/fertilizer manufacturing.

Phosphorus Removal by UF



Nitrogen Removal by UF



For this project, **we propose to build and operate a pilot-scale ultrafiltration system using the identical porous stainless steel tubes but in a scaled-down system that can be easily transported on a trailer from farm-to-farm.** A CAD drawing of the skid we purpose-designed for this project is provided below. This unit can easily be hooked up to process material from existing lagoons or process tanks, or connected to a tote that is filled with liquid manure or digestate. With about 52 ft² of filtration area, **this unit could process about 1,000 gallons of manure into 800 gallons of UF permeate and 200 gallons of UF concentrate each day** (about the volume of manure from 30 cows). We have three Vermont dairy

farms and a composter that have agreed to host the unit for onsite demonstration trials as part of this project (please see attached letters of support). We envision running the unit at each farm for about two weeks each, collecting performance data and taking samples for lab analysis of the total solids, suspended solids, and nutrients (NPKS). The UF concentrate produced at each facility would then be taken to Vermont Natural Agricultural Products (Robert Foster's composting operation) for compost trials.



CAD drawings of proposed pilot ultrafiltration unit for this project

Mass Balance, Cost Estimates, and Hub-and-Spoke Model:

To better understand how this technology can address phosphorus contamination of Vermont waterways, we have modeled the mass balance for a typical 500-head dairy farm with an expected volume of liquid manure (after screw-pressing) of about 15,000 GPD. Using a typical analysis for liquid manure from a screw-press (based on our testing at numerous farms), we predicted the total solids (TS), total khedjahl nitrogen (TKN), total phosphorus (P2O5), and total potassium (K2O) for the filter influent as 3.8% TS, 20 lbs/1,000 gal TKN, 8.8 lbs/1000 gal P2O5, and 18.8 lbs/1000 gal K2O. Using actual UF permeate data from pilot testing, we then estimated the UF permeate and UF concentrate compositions as well as pounds per year of each nutrient for this site.

As shown in the table below, the UF concentrate is predicted to be about 14.5% TS with 43 lbs/1000 gal P2O5. This represents about a 5x concentration of phosphorus and accounts for 98% of farm's phosphorus. **So instead of the farm's 48,100 lbs of P2O5 being distributed in 5,475,000 gallons of manure each year, now nearly all of that phosphorus is in just 1,095,000 gallons of UF concentrate.** This makes the phosphorus easier to manage and less likely to end up in Vermont's waterways. Some of the opportunities include:

- Precision application of phosphorus-rich UF concentrate to soils, including those further away from the farm that are typically lower in phosphorus (and therefore more likely to absorb the phosphorus instead of letting it runoff)
- Lower-cost irrigation of UF permeate which is low in phosphorus (and devoid of suspended solids and pathogens)
- Sales of the UF concentrate to nearby farmers or other businesses that may benefit from its use
- Transport and sale of the UF concentrate to nearby fertilizer manufacturers and/or composters, who will use it to top-dress piles or boost the nutrient content of their products

Estimated Mass Balance of Ultrafiltration System for 500-Head Dairy

TS	Volume (GPD)	Concentration (lbs/1000 gal)	Concentration (%)	Amount (lbs/year)	Percent of Mass in Manure (%)
Liquid Manure	15,000	320	3.8	1,752,000	
UF Permeate	12,000	97	1.2	424,860	24%
UF Concentrate	3,000	1,212	14.5	1,327,140	76%
TKN					
Liquid Manure	15,000	20.0	0.2395	109,500	
UF Permeate	12,000	10.8	0.129	47,304	43%
UF Concentrate	3,000	57	0.680	62,196	57%
P2O5					
Liquid Manure	15,000	8.8	0.1054	48,180	
UF Permeate	12,000	0.17	0.002	745	2%
UF Concentrate	3,000	43	0.5	47,435	98%
K2O					
Liquid Manure	15,000	18.8	0.2251	102,930	
UF Permeate	12,000	18.3	0.22	80,154	78%
UF Concentrate	3,000	21	0.25	22,776	22%

The cost to operate the UF system is estimated to be 0.5 to 1 cent/gallon of manure filtered, depending on the cost of local electricity and the thickness of the manure being filtered. For the 500-head example presented above, the annual costs would range from \$27,375 to \$54,750. This is equivalent to **\$0.58 to \$1.15 per pound of phosphorus removed from the liquid manure and concentrated into the UF concentrate product**.

Based on recent commercial fertilizer prices, the value of one pound of traditional P2O5 is about \$0.522. **Since our process involves no chemical additives, the UF concentrate can be used on organic-certified farms and incorporated into organic-certified composts and soil amendment products, where the value of a pound of P2O5 is even greater.** This suggests that a farm utilizing ultrafiltration could likely cover the operating costs of the system simply by selling the UF concentrate on its P2O5 content. Since it also contains other nutrients of value, the UF concentrate presents a potential new revenue source for a farm utilizing ultrafiltration.

While we have not yet had detailed conversations with potential buyers, we do believe there is a strong market in Vermont for the UF concentrate product. One major composter, Robert Foster, has reviewed the predicted analysis of the UF concentrate and believes it would make a good addition to many of his compost products. He also has the knowledge and background to best recommend new formulations, blends, and mixes that we can utilize to create the highest value co-products which help stabilize the phosphorus and export it from sensitive areas. Other's working in Vermont, such as Agrilab Technologies, are also supporting this effort to help composters like Fosters better utilize the heat energy from composting to create drier, more stable products that can be transported further distances.

As part of this project, we will work with Fosters and Agrilab Technologies to convert UF concentrate generated at nearby farms into a variety of finished compost products to better understand which blends perform best and what economic value there would be to the farm generating the UF concentrate and the composter/fertilizer manufacturer.

We will also create a more detailed map of potential dairy farms within a 25 and 50-mile radius of Vermont Natural Ag Products. For example, Monument Farms Dairy (see attached letter of support) is just 6.3 miles away. Dubois Dairy Farm (see attached letter of support) is 12.9 miles away. **We envision a hub-and-**

spoke type model in which dairy farms use onsite ultrafiltration to concentrate phosphorus and then transport some or all of it to a central location (such as Vermont Natural Ag Products) for processing (which may include composting, blending, drying, packaging, etc.).

Education, Outreach, and Reporting:

Upon implementation of our filtration solution, we will also host tours and educational events in partnership with local trade groups and state agencies. These will engage nearby stakeholders in the watershed, including other farmers, agency employees, monitoring staff, etc. One-page handouts describing the results from on-going operations and testing will be prepared and distributed. Ideally, we could also partner with teams at Middlebury or UVM or other research institutions to better quantify agronomic impacts and runoff reductions. Attendees interesting in learning more about the technology for their farm will be cataloged and contacted to get specific sizing and proposals generated. An online dashboard will be available to the farm and the public (see example screen shot to right) so real-time and summary data on how many gallons of manure were processed/concentrated and the corresponding nutrient changes.



As part of the implementation, we will also perform market research to determine the highest value for the concentrated fertilizer, be it as a compost top-dressing, a feedstock for dry fertilizer manufacturing, an organic fertilizer, etc. This will involve finding suitable buyers within a 100-mile radius of the project site and generating the mock-specification sheets (based on actual analyses) required to introduce the product to potential buyers. Buyers outside of the watershed will be targeted when possible (to completely remove phosphorus from the watershed). The number of buyers identified, the volume they would buy, and the price they'd be willing to pay, and the cost to deliver the product to them will be quantified and compiled into a report summarizing the project. These data will be used to inform the farm about the best use of the fertilizer product. Likewise, research will be conducted on the farm and with farm-equipment vendors to determine if changes to how the farm spreads the UF permeate can be instituted to reduce the cost of manure spreading overall.

Project Staff (see additional resumes attached):

Robert Levine, Ph.D. (CEO): Founded Digested Organics in 2013 after graduating from University of Michigan with a Ph.D. in Chemical Engineering. Previously, Robert graduated from Middlebury College in 2008 with a degree in Microbiology and Biochemistry and completed a thesis on using nutrients from anaerobic digesters on VT dairy farms to grow algae and make biodiesel. Recently wrote and was awarded the only discharge permit ever granted to a farm to discharge water purified from manure into a US waterway (by EPA and WI DNR). Will lead the effort to assemble, install, and commission the system for this program.

Ian Charles, Ph.D. (Mechanical/Electrical Engineer)—25+ years in C-level management, successful entrepreneur in cleantech space. Ph.D. Mechanical & Control Systems Engineering; will produce engineering drawings for the system, oversee assembly and onsite installation.

Matthew Biette (Business Development, Northeast USA): Matthew ran Middlebury College's dining halls for many years and is intimately familiar with many farms throughout the state. He has been working with several agencies throughout the state to promote digesters and filtration solutions for manure.

Budget Description:

Sources and Uses	Requested Funds	Match and Source of Commitment	Total Project Budget
Personnel	\$0	\$25,000 (Digested Organics)	\$25,000
Equipment	\$43,000	\$0	\$43,000
Travel	\$5,000	\$0	\$5,000
Lab Testing	\$1,500	\$0	\$1,500
TOTAL	\$49,500	\$25,000	\$74,500

The largest portion of the grant will be spent to manufacture the ultrafiltration equipment and ship it to Vermont. Digested Organics will provide staff time to design, manufacture, and operate the pilot unit on Vermont dairy farms for 6-weeks (two-weeks per farm at three different dairies), as well as generate a summary report. The budget also includes an allocation for travel for Digested Organics staff (some would come from Michigan and some are local to Middlebury, VT) as well as lab testing to determine the nutrient content of the manures being filtered and the ultrafilter products, along with the compost products generated.

Each testing site would also provide some cost share, in terms of onsite staff assistance and utilities (power and water). The three sites include:

- Monument Farms Dairy
- Dubois Dairy
- Foster Brother's Farm

The UF concentrate would be processed by Vermont Natural Ag Products, who will also provide cost-share by assisting with compost trials involving the UF concentrate.

Letter of Support

From: Robert Foster
Foster Brothers Farm
58 Lower Foote Street
Middlebury, VT 05753

From: Robert Foster
Vermont Natural Agricultural Products
297 Lower Foote Street
Middlebury, VT 05753

To: Robert Levine
Digested Organics
PO Box 3386
Ann Arbor, MI 48103

Re: Vermont Phosphorus Innovation Challenge

Dear Dr. Levine,

We appreciate you reaching out to our facility regarding your innovative ultrafiltration system for dairy manure. As you know, we produce thousands of gallons of liquid manure each day and it is rich in phosphorus, a nutrient we need to help grow our crops. Yet we are also aware that phosphorus can leach from soils and end up in our waterways and lakes, where it can lead to algae growth and impair recreation. As a family who has farmed in this watershed for many years, we would like to help keep our waterways and lakes clean.

We understand that your company produces a stainless-steel ultrafiltration system that can process liquid dairy manure, turning 100 gallons of manure into about 75 gallons of filtrate and 25 gallons of concentrate. Your data suggests that the filtrate contains very low levels of phosphorus (typically <0.3 lbs/1000 gal), as well as no pathogens and no suspended solids. We believe this technology could be used to help remove phosphorus from the majority of our liquid manure while concentrating the phosphorus into a product we can apply to our composting piles. As you are aware, we run a composting facility that is uniquely suited to process this material and help develop formulations appropriate for sales and export. We see this as an opportunity to grow our business and be a centralized processing facility for concentrate produced on farms nearby.

We would be excited to host a demonstration of this technology at our farm and/or composting facility. We understand that this will entail a small trailer-mounted unit being onsite and plugged in and that we would provide liquid manure to this system on a daily basis. We will also accept concentrated manure produced on other farms and show how this can be appropriately composted.

Overall, we are excited to help participate in the Vermont Phosphorus Innovation Challenge and we look forward to working with you.

Sincerely,



Robert Foster

Letter of Support

From: Monument Farms Inc.

To: Robert Levine
Digested Organics
PO Box 3386
Ann Arbor, MI 48103

Re: Vermont Phosphorus Innovation Challenge

Dear Dr. Levine,

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We would be excited to host a demonstration of this technology at our farm. We understand that this will entail a small trailer-mounted unit being onsite and plugged in and that we would provide liquid manure to this system on a daily basis.

Overall we are excited to help participate in the Vermont Phosphorus Innovation Challenge and we look forward to working with you.

Sincerely,


Monument Farms Inc.

From: Dubois Farm, Inc.
2038 Route 17 E
Addison, VT 05491

To: Robert Levine
Digested Organics
PO Box 3386
Ann Arbor, MI 48103

Re: Vermont Phosphorus Innovation Challenge

Dear Dr. Levine,


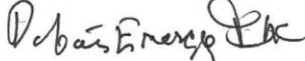
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Overall we are excited to help participate in the Vermont Phosphorus Innovation Challenge and we look forward to working with you.

Sincerely,

July 2, 2018

To whom it may concern,

This letter is to indicate our support of the Digested Organics proposal for the Vermont Phosphorus Innovation Challenge (VPIC). Dr. Robert Levine and Matthew Biette have developed innovative technology that has had excellent performance recovering phosphorus (P) from dairy manure as indicated by sampling results and installations outside of Vermont. While Agrilab Technologies Inc. is submitting an independent proposal to VPIC, we believe there are promising synergies between our efforts.

Digested Organics technology is particularly attractive for our efforts since their process does not require polymers or synthetic inputs to concentrate P. As some of the products we intend to develop would need to be approved for use in organic production, their P-rich Ultrafilter concentrate is of great interest to our planned work with VT Natural Ag Products and others.

Please support the proposal submitted by Digested Organics and we hope to work with their team on this project.

Sincerely,

Brian Jerose, President, Agrilab Technologies Inc.